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IGY BULLETIN

A monthly survey of programs and findings of the International Geophysical Year and the International Geophysical Cooperation–1959 as related primarily to United States programs. The Bulletin *also reports on international programs in geophysics and space science that have grown out of the IGY, and on their results.*

Even before the end of the observational phase of the IGY—July 1958 through December 1958—it was apparent that analysis of the great body of accumulated data would require an extended period of time. Moreover, the continuation of many IGY programs during IGC-59, and the numerous successor world-wide geophysics and space-science programs that have grown out of or gained stimulus from the IGY, are adding new dimensions to the over-all geophysical picture. Accordingly, on recommendation of the American Geophysical Union, endorsed by the US National Committee for the IGY, and with support from the National Science Foundation, publication of the *IGY Bulletin* is being continued in order to complete the record of reports on results of IGY and IGY-related studies.

The original aim of the *Bulletin* was primarily to keep participating scientists informed of progress in the United States program and, to the extent possible in the limited space available, in the programs of other countries. During the first few months of publication, however, a large number of students, teachers and other interested persons asked to be permitted to subscribe to the *Bulletin*, and near the end of its first year of publication the *Bulletin* was accordingly made available on a subscription basis. (See back page of this issue for subscription information.)

The *Bulletin* is also reprinted in the *Transactions of the American Geophysical Union*, thus widening its circulation in the scientific community and helping to keep scientists informed of developments in geophysical disciplines related to their own. All in all, nearly 15,000 persons read the *IGY Bulletin* each month.

Through reports on aims, plans, instrumentation and techniques, early *Bulletins* provided background on each IGY discipline, as well as on initial progress in getting IGY programs under way. Also included in earlier issues were short background reports on sub-disciplinary subjects such as whistlers, sunspot numbers, and airglow. Following these first few issues, *Bulletin* reports have been increasingly concerned with scientific results of specific IGY projects. Whenever possible, the reports have been related to the scientists and institutions conducting the experiments; their cooperation has been very largely responsible for the *Bulletin's* success.

With this issue, the *Bulletin* begins its fourth year of publication. Future issues will make available IGY findings not yet reported in these pages, as well as those still to be revealed by analysis of the great storehouse of IGY and IGC-59 data. In addition, plans for related investigations in geophysics and space research, and the results which are emerging from these successor world-wide programs, will be reported. The *Bulletin* will also continue to review developments of interest contributing to the advancement of international cooperation in geophysical research.

—Hugh Odishaw, Executive Director, US National Committee for the International Geophysical Year, National Academy of Sciences.

Electrical Current in the Polar Ionosphere

The following report is based on material prepared by Laurence J. Cahill, Jr., University of New Hampshire. A more detailed account appeared in the Journal of Geophysical Research, *October 1959. Dr. Cahill was associated with the State University of Iowa at the time the studies were made.*

As part of an IGY program to investigate electrical currents in the ionosphere, the State University of Iowa (SUI) conducted a number of rockoon flights in the Arctic, Equatorial Pacific, and Antarctic in the summer and autumn of 1957. *Bulletin No. 25* describes the results of the Equatorial Pacific flights, which penetrated the Equatorial electrojet, and briefly reviews the theory relating ionospheric electric currents to variations in the earth's magnetic field.

During the Arctic region investigations, a magnetometer flight reached the lower ionosphere during a magnetic storm. It provided the first high-altitude magnetic measurements made in or near the auroral zone. This flight, SUI Flight 59, was launched from the helicopter deck of the *USS Plymouth Rock* on August 6, 1957. At the time of launch, 1603 UT, the ship was at about 64°N, 56°W, in the Davis Strait between Greenland and Canada (see Fig. 1). The rocket was fired 80 minutes later, when the balloon was at an altitude of 23 kilometers, and reached a maximum altitude of about 127 kilometers.

Advice and assistance were provided by James A. Van Allen and other SUI scientists. Navy personnel of the *USS Plymouth Rock* cooperated in launching the flights. Ground-station magnetic records, for correlation and comparison, were obtained from Dr. Karl Anderson of the Meteorologisk Institut, Denmark (Godhavn, Greenland, records), and from the Dominion Observatory, Canada (Baker Lake, Canada, records).

Flight Results

Measured values of the earth's magnetic field during Flight 59, after correction for rocket spin, are plotted against altitude in Figure 2. More than 200 individual measurements were made during the flight. Below a height of 90 kilometers, the magnetic record follows approximately the normal inverse-cube decrease of geomagnetic intensity with altitude. An additional decrease, indicated by the divergence of the upward and downward records in Figure 2, resulted from the rocket's horizontal motion to the southeast, toward a region of lower intensity of the total magnetic field.

The abrupt slope-change between 90 and 100 kilometers in the record of the upward leg of the flight marks the rocket's entrance into an electrical current sheet. This slope change, combined with the fact that general

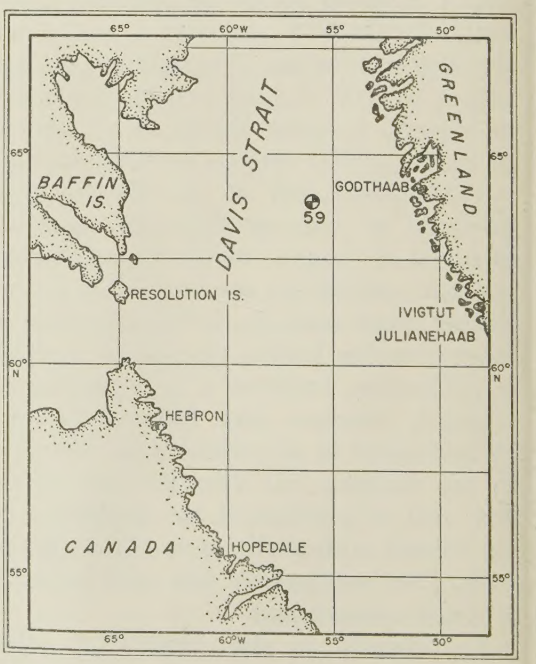

Fig. 1. *Davis Strait Region, Between Canada and Greenland, Showing Location of SUI-IGY Rockoon Flight 59.*

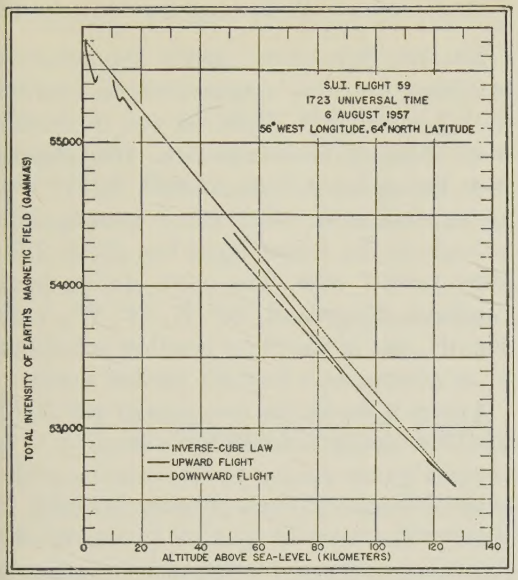

Fig. 2. *Magnetic-Field Intensity Plotted Against Altitude for Flight 59.*

features of the current were found to be the same on both the up and down legs of the flight, even though the two legs were separated horizontally by several kilometers, indicates that the current had considerable lateral extent. A narrow ribbon- or filament-type current, such as those associated with auroras, would produce effects of a different nature.

The gap in the downward record between 117 and 92 kilometers resulted when the angle between the magnetic-field vector and the magnetometer coil became too small for reliable measurements. Rough measurements of proton precession frequencies with a narrow-band frequency analyzer, however, show the record for this gap to be essentially coincident with that for the upward leg. (In the proton precession magnetometer, such as that used on Flight 59, a magnetic-field measurement is obtained as an easily telemetered audio frequency—the gyromagnetic precession frequency of protons in a suitable liquid.)

The slope of the magnetic record at peak rocket altitude did not show a distinct return to that at altitudes beneath the current sheet. Hence, the current layer was not completely penetrated and apparently extended above 127 kilometers. Fluctuations of the measurements near peak altitude, which are easily seen in more detailed records, probably resulted partly from time variations in the magnetic field. Such variations would be more evident near the top of the rocket's flight, where altitude changes are slower.

Intensity and Structure of Current

The magnetic dip angle—the angle between the lines of force of the magnetic field and a horizontal surface—at the flight location is about 80°. Thus, the horizontal current sheet represents a small horizontal vector added to the nearly vertical vector of the total magnetic field.

At peak altitude, the strength of the total magnetic field departs by 90 ± 20 gammas (γ) from the value to be expected in the absence of the horizontal sheet current. The smallest change in the horizontal magnetic field that could cause this change in the total field is 520γ. In this case, the 90γ change in the total magnetic field would occur if the horizontal vector of the sheet current exactly paralleled the horizontal component of the total field but pointed in the opposite direction for positions lying below the horizontal current sheet.

With respect to the flight location, the magnetic north pole is 45°W of geographic north. Hence, the azimuth of the horizontal component of the total magnetic field at the flight location is 315° from true north, or toward the northwest; the direction of the horizontal vector of the sheet current would be 135° true azimuth, or southeast; and the direction of flow of the sheet current itself would be 225° true azimuth, or southwestward (see Fig. 3).

A current producing a 520γ change in the intensity of the horizontal component of the magnetic field at rocket altitude would contribute a variation of 260γ to the horizontal component at ground level. However,

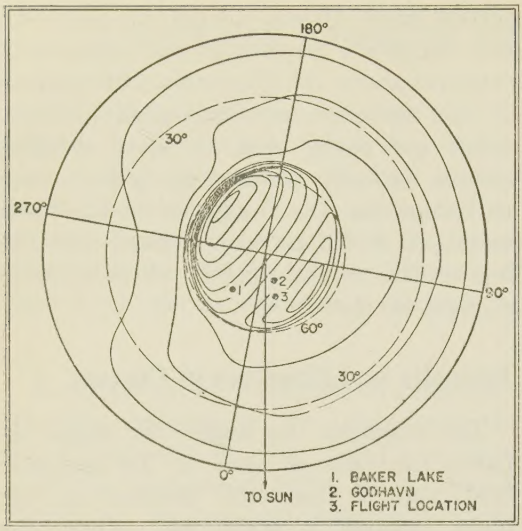

Fig. 3. *Northern Hemisphere Current System for Geomagnetic Storm of May 1, 1933 (after E. H. Vestine). System is centered over geomagnetic pole, and 0° meridian is one running through geographic north pole. Current flows clockwise on dawn side of auroral zone and counterclockwise on twilight side. Locations of Flight 59 and ground stations are indicated by numbers.*

as overhead currents are thought to cause only 2/3 of the total ground-level variation, a total variation of 390 ± 90γ might actually be observed at the ground. In the vicinity of this flight, moreover, an even larger variation might be expected at the ground since the current layer was apparently not entirely penetrated by the rocket. In addition, a current direction appreciably different from 225° would require still larger intensity variations in the horizontal component, as well as greater current density, in order to produce the 90γ change in the total field. A current direction of 165°, for example, would require a current density twice that for the 225° azimuth and would produce a ground-level variation of 780γ.

Assuming an azimuth of 225° for the current direction, the average current density of the current layer would be approximately 11 amperes/km^2. The current density appears to vary with height.

Comparisons with Ground-Level Records

Records from two Arctic ground-level stations, for the magnetic-storm period during which SUI Flight 59 was in the air were obtained for comparison. One station is at Baker Lake, Canada (64° N, 96° W), at approximately the same geomagnetic latitude as the rocket flight but about 2700 miles farther west. The other station is at Godhavn, Greenland (69° N, 54° W), only slightly east of the flight location but about 5° of geomagnetic latitude farther north.

Figure 3 shows the locations of the flight and the two ground stations relative to a current system similar to that existing at the time of Flight 59, but possibly differing in detail. The current system shown in the figure, an electrical-current representation of surface magnetic variations, was prepared by E. H. Vestine for a magnetic storm on May 1, 1933. (Azimuths shown in the diagram do not represent normal geographic directions.)

The horizontal-component variation observed at Godhavn at the time of the rocket flight was approximately 300γ, which agrees reasonably well with the variation of 390 ± 90γ computed for the ground value at the flight location. Some lack of agreement between the two locations might have been expected because of local differences in the density of the overhead current. The equivalent variation at Baker Lake was about 500γ and, because of its location, Baker Lake would have observed the same main features of the magnetic storm two to three hours later than they were observed at the flight location.

Conclusions

The simplest explanation for the results of SUI Flight 59, conducted at a geomagnetic latitude a few degrees above the auroral zone, is that they were caused by a horizontal current layer—the "polar cap current"—flowing southwest. This interpretation is consistent with both the rocket and ground-level observations.

Possibly, however, the flight location was farther south relative to the August 6, 1957, current system than for that shown in Figure 3. In this case, the rocket results might have been produced by an increase in current density as the polar cap current funneled into the eastward-flowing auroral arc; the current direction might then have been south or southeast. Another possible interpretation of the rocket results, pointed out by another investigator, is that they could also have been produced by a horizontal, circular, pancake-shaped current, rather than a sheet current.

International Indian Ocean Expedition

The following material is essentially a condensation of a preliminary prospectus prepared by the Special Committee on Oceanic Research (SCOR) of the International Council of Scientific Unions (ICSU) and released by the White House on June 13, 1960.

An international expedition to the Indian Ocean, one of the least known oceanic regions of the world, will begin late this year and extend through 1964. The Indian Ocean is one of the world's last unexplored frontiers. Since 1873, fewer than two dozen vessels have carried out oceanographic investigations there. Modern techniques have been used only in limited areas, leaving great gaps both in areal coverage and in the nature, intensity, and accuracy of observations. No systematic study has yet been attempted, and the combined profiles of observations reported thus far give only a preliminary picture of the Ocean's behavior and characteristics.

The Indian Ocean offers a vast environmental laboratory extending from polar through tropical waters and divided in its northern part into small oceans, each subject to radical seasonal wind reversals. It is a complete ocean system, yet small enough to be studied as a whole. Thus, it offers unparalleled opportunity for a wide variety of specialized investigations. Although too large for a single nation's efforts, it is ideal for an international cooperative endeavor.

Like the IGY and IGC-1959, the International Indian Ocean Expedition is a many-sided scientific attack on a single area of interest; the Expedition is under the leadership of SCOR (Special Committee on Oceanic Research) of the International Council of Scientific Unions. Scientific responsibility for United States participation is borne by the Committee on Oceanography of the National Academy of Sciences—National Research Council. Key contributions are being made by the Department of the Navy and the National Science Foundation. The Navy is supporting the operation of oceanographic research ships now in use by United States oceanographic institutions. The Foundation is responsible for planning and coordinating Federal support for United States participation in the program, including financial support over and above regular ship operating costs.

The Indian Ocean

Physical Characteristics: Although its 28,000,000-square-mile area constitutes more than 14% of the earth's surface, relatively little is known about the Indian Ocean. Only the most general features of its bottom topography and circulation and of the distribution of its living organisms are known. More than 300 times as many bathythermograph observations have been made in the North Atlantic as in the Indian Ocean; moreover, almost half of this extensive

marine region has had no biological sampling, and in most of the remainder only 1 to 4 observations have been made per 100,000 square miles.

The Indian Ocean has several unique characteristics. Nowhere else in the world is there a similar seasonal reversal of the prevailing wind. That part of the Ocean lying north of the equator is characterized by the two monsoons, one blowing from the northeast for approximately six months and the other from the southwest for the remainder of the year. This phenomenon has a powerful but essentially still-unknown effect upon the currents and upon marine organisms.

Another notable feature is the apparently high productivity of this Ocean. In June 1957, a Russian ship not far from the main trade route between Ceylon and the Gulf of Aden (see Fig. 4) reported millions of tons of dead fish floating in an area some 600 miles long and 120 miles wide extending across the middle of the Ocean. Similar reports came simultaneously from British ships in the region, and during the same year, smaller fish kills were also reported in nearby parts of the Arabian Sea. It is not known how the fish were killed, but the very size of this catastrophe gives some idea of the potential mid-ocean resources, which are currently untapped.

Socio-economic Characteristics: The tropical and sub-tropical regions surrounding the Indian Ocean contain many of the world's densely populated countries. Over a quarter of the world's people live in these countries, and their populations continue to grow rapidly.

Population pressures on the existing food supplies result in the prevalence of protein deficiency diseases in India, Ceylon, Indonesia, Malaya, and parts of the east coast of Africa. Some of the nations bordering the Indian Ocean have a seafaring tradition and conduct extensive coastal fisheries. To feed their growing populations will require expanding these fisheries.

Expedition Design

Participation: Under the non-governmental sponsorship of the International Council of Scientific Unions (ICSU) and its Special Committee on Oceanic Research (SCOR), scientists of the various participating nations will staff vessels provided by marine laboratories of these nations. Scientists from countries where research vessels are unavailable will be invited to work on the Expedition's ships, and special efforts will be made to obtain active participation by each nation bordering the Indian Ocean.

As never before, intensive training and experience in oceanographic research are available to residents of this maritime area. Possibly 20 vessels, with facilities for about 350 scientists, will participate in the Expedition. (Figure 4 is a track chart of the Indian Ocean showing cruises scheduled to be completed by January 1, 1961.) Exchange of scientists between ships, and partial cruises by individuals, will increase the number receiving training and will vary their experience. Data-processing centers and biological classification laboratories are planned to serve as nuclei for post-Expedition scientific development around the Indian Ocean.

As of June 1, 1960, the following nations had formed national committees of SCOR and had announced plans to send ships and scientific parties on the Expedition: Australia, Ceylon, France, German Federal Republic, India, Indonesia, Japan, Pakistan, Union of South Africa, Union of Soviet Socialist Republics, United Kingdom, and United States of America. National committees of the following additional countries plan to contribute scientific parties: China (Taiwan), Denmark, Israel, The Netherlands. Other countries are now forming national committees and may also announce plans to participate.

Timing: The period of peak activity will occur in 1962 and 1963. Preliminary plans will be completed by August 1960 and the

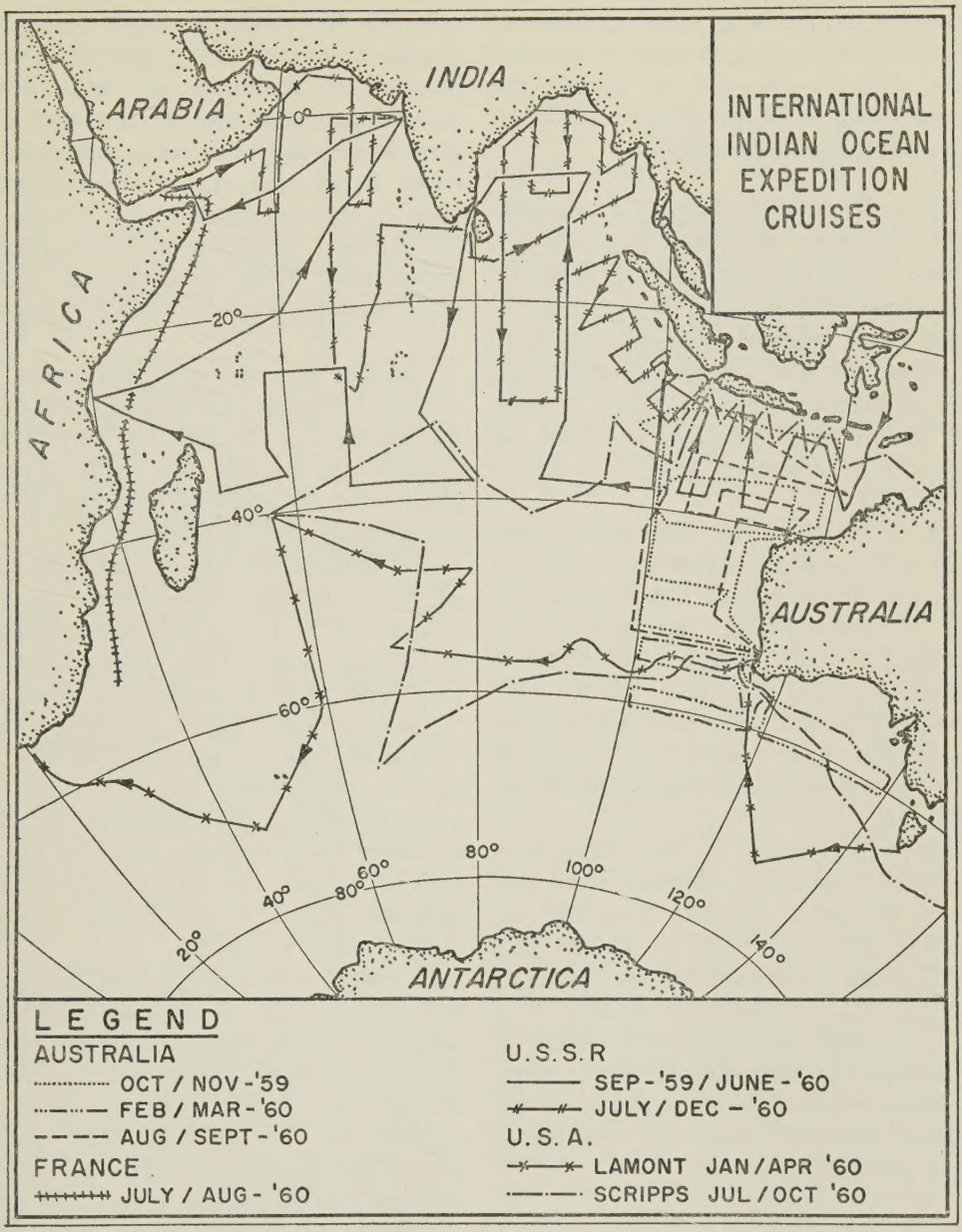

Fig. 4. *Indian Ocean, Showing International Expedition Cruises to be Completed by January 1, 1961.*

first cruises in the coordinated effort will occur in late 1960. The Expedition will continue into 1964 and data analysis will undoubtedly go on still longer. An atlas incorporating the full findings is contemplated.

Because of the present scarcity of information on the Indian Ocean, continuous revision and re-examination of plans will be needed as new data are acquired. Every effort will be made to complete preliminary processing and analysis of data within six to eight months in order to re-direct subsequent cruises. This plan, together with the

importance of obtaining series of observations of the same areas in different seasons, makes it more desirable to spread the program over several years than to conduct a single, major simultaneous effort.

Procedure: A preliminary and tentative cruise pattern for the entire Indian Ocean has been agreed upon by members of SCOR and participating National Committees. In regions where seasonal differences owing to the monsoons are significant, ships will cruise twice along the same track. To complete the pattern will require about 10 ship-years of operation over a total of 180,000 miles.

Uniform standards for observation techniques and instrumentation will be established, and exchanges of scientists between ships of participating nations will be arranged. Existing World Data Centers, established during the IGY, will be used as repositories, and new biological centers for analysis and custody of biological specimens will be established in the Indian Ocean area.

Ships participating in the Expedition will devote at least half their time to investigations within a specially designed coordinated grid, and half to independent investigations determined by the scientists involved. The intensity of studies in a given area will depend on the nature of the phenomena anticipated; thus, many more observations may be expected in the boundary currents along the continental borders than in mid-ocean.

Areas of Study

Physical Oceanography: Several fundamental oceanographic problems can be studied more efficiently in the Indian Ocean than elsewhere because of the seasonal reversal of winds. Thus, understanding the oceanic processes here will contribute to a knowledge of all oceans. It is planned to study many basic questions such as: How long does it take the winds to set up a current? How rapidly does this current deepen with time? What part of the energy required to maintain an ocean current comes from the winds and what part comes from the horizontal density gradients that result from regional climatic differences? How do internal friction, and friction with the bottom, influence the velocity-depth distribution? What is cause and what is effect in the general circulation of the oceans?

Chemical Oceanography: Systematic collection of physical and chemical data during the survey will for the first time make it possible to describe the distribution of plant nutrients and dissolved organic compounds in the Indian Ocean.

The Indian Ocean is in a vast basin closed off from exchange with other seas north of about 40° S. Into it pour great quantities of drainage waters from the land carrying their burdens of substances dissolved from the rocks and soil. Hence, the Indian Ocean is an ideal place to study the effect of run off on the composition of sea water. For example, studies of elements that have relatively short residence times in the sea, such as copper and barium, should show markedly higher concentrations here than in the Pacific or Atlantic.

In recent years, geochemical techniques have added much to our understanding of oceanic residence times and of the rates of exchange between surface and deep waters. During the Indian Ocean Expedition, samples will be collected for carbon-14 dating, for analysis of carbon and oxygen isotopes, and for radium assay. This survey of an entire ocean, using geochemical "tracer" techniques, will permit a much better evaluation of the circulation than has previously been possible.

Meteorology: The meteorological objective is to obtain increased understanding of the energy exchange between sea and atmosphere, particularly near the air-sea boundary. To this end, basic research will be carried out on radiation input and on interaction of

atmospheric pressure, winds, cloudiness, rainfall, and evaporation with temperature, movement, and roughness of the sea. A SCOR working group is drafting a list of desirable objectives in conjunction with various meteorological organizations.

Marine Biology: In addition to its effect on the circulation of near-surface waters, the monsoonal reversal of winds is believed to have important biological repercussions. Under its influence, regions of upwelling and of high productivity should develop, decay, and shift from place to place, causing dramatic changes in the distribution and abundance of marine organisms. The Indian Ocean Expedition observations may make it possible to anticipate these changes. Nowhere else in the world's oceans is it possible to study the interaction of atmosphere and biosphere on such a scale.

Standard biological collections and measurements made systematically over the whole ocean will define its biological "structure," the three-dimensional distribution of plants and animals. Integration of these observations will permit assessment of the living resources. It will also provide the basic biological information—such as the distribution of fish eggs and larvae, and of fish food—that is essential to the eventual understanding of fluctuations in the abundance and availability of commercial fish.

Since World War II, great advances have been made in techniques for measuring primary production of the minute organic matter that constitutes the basic food for larger marine life. The widespread, systematic use of these methods by the ships of the Expedition will help in assessing, for the first time, the fertility of the Indian Ocean.

Marine Geology and Geophysics: Except for data collected during the IGY, the bottom topography and crustal structure beneath the Indian Ocean are virtually unknown. Old soundings delineate major structural components comparable to those of the Pacific and the Atlantic—trenches, undersea mountain ranges, a mid-ocean swell, and, possibly, fracture zones. Marked differences exist between the Atlantic and the Pacific Oceans, however, with respect to the arrangement of these components and to their relationship to the structures of the bordering continents. It is not known whether the Indian Ocean more closely resembles the Pacific or the Atlantic ocean. Precise modern soundings, in addition to clarifying this question, will be of immediate use in providing a base map for all the other studies as well as the data necessary for navigational charts. It is even possible that they may uncover rich shallow-water fisheries at considerable distances from shore.

Integrated geophysical studies—of the areal pattern of heat flowing from beneath the crust, the gravity field, the crustal thickness, and magnetic characteristics of the oceanic and border areas—will furnish basic information related to problems of ocean and continent development. Intensive coring, dredging, and bottom photography will yield data on processes of sedimentation and productivity; on climatic and magnetic changes during the last several million years; and on the distribution of manganese nodules, which are potential ores of manganese, nickel, and cobalt.

Geologic Investigation of the Central Horlick Mountains, Antarctica

The following material is based on a more detailed report by William E. Long, glaciologist at IGY Byrd Station during the 1957–58 season and member of the 1958–59 over-snow traverse team from Byrd Station. The original report was issued by the Ohio State University Research Foundation as USNC-IGY Antarctic Glaciological Data Report Number 2, Part VII, Preliminary Report of the Geology of the Central Range of the Horlick Mountains, Antarctica, *September 1959.*

The Horlick Mountains extend eastward from the southeast corner of the Ross Ice Shelf for a distance of about 250 miles. They lie approximately along the 85° S parallel of latitude roughly between 130° and 85° W longitude (see Fig. 5). Prior to the IGY, the Horlick Mountains had been seen only a few times and from considerable distances. Hence, very little was known about their exact location, extent, height, and geologic nature.

During a reconnaissance flight over the route of the Byrd Station 1958–59 IGY over-snow traverse, which was scheduled to pass along the front of the Horlick Mountains, the sedimentary aspect and structure of the central portion of the mountains was noted. Plans were made to include a visit to this region during the traverse.

The traverse party of six left IGY Byrd Station in three Sno-Cats on November 1, 1958, to make seismological, glaciological, and geological investigations of the ice cap and of projecting bedrock areas (see *Bulletin No. 25*). The traverse reached a position about three miles from the mountains in early December, and a base camp was established. Four members of the party, C. R. Bentley (traverse leader), J. B. Long, F. L. Darling, and W. E. Long, then made a reconnaissance geological investigation of the mountains. They climbed 4000 feet to the summit of Mount Glossopteris, tentatively so named for the characteristic plant fossils found there, making rock-sample collections and measuring elevations and attitudes of the rock beds. The summit was marked with a six-foot redwood beam, and a container with the party identity and date was placed at the base of a small cairn built on the highest rock surface, just west of the snow summit.

Surveying and mapping of the mountains here and along the entire traverse was accomplished by US Geological Survey cartographer William Chapman, using a theodolite. G. A. Cooper helped in later analysis by dating the fossil brachiopods (marine, shelled animals); James Schopf, US Geological Survey, assisted with paleobotanical dating and advice; Samuel Treves, University of Nebraska, advised and aided with rock identifications and interpretations; and Warren Hamilton, US Geological Survey, analyzed a basement-rock specimen.

Geography

The Horlick Mountains are a continuation of the mountain chain that extends from Cape Adare, at the northeast end of Victoria Land, along the eastern border of Victoria Land to the Queen Maud Range, south and southeast of the Ross Ice Shelf (Fig. 5). The structure and rock types are strikingly similar throughout the entire mountain chain. The mountains are massive, tabular blocks, in most places bounded on the north by imposing escarpments and sloping gently toward the south.

The area marked Horlick Mountains on older maps consists of three ranges, each including numerous peaks. The westernmost range has the highest summits, reaching elevations of about 12,800 feet, with approximately 5000 feet of relief between the ice-cap surface and the summits. Peaks of the

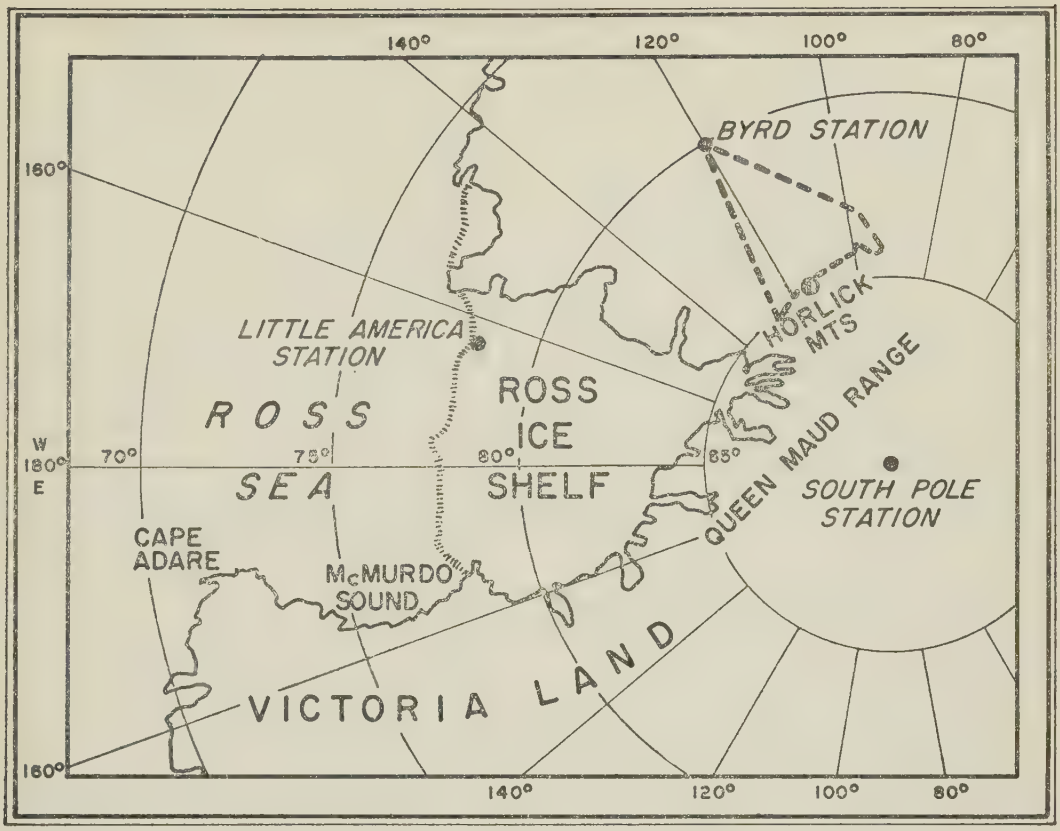

Fig. 5. *Route of 1958–59 Byrd Station Traverse, (dashed line), Showing Position of Horlick Mountains and Location of Area Studied (half-shaded circle).*

central range are generally about 10,000 feet in elevation, with 4000 feet of relief between the peaks and the snow surface. The eastern Horlick range consists of 8000- to 9000-foot peaks and relief is about 3000 feet.

The central Horlick range, in which the area of study was located, is about 20 miles long and 5 to 10 miles wide. Peaks of the central range form an asymmetrical arc concave toward the south. Inside this mountain arc, is a raised ice plateau with an elevation of about 8000 feet and a width of 10 to 15 miles.

Bedrock is well exposed on mountain slopes, where the strong winds prevent accumulation of snow. Moreover, no lichens or other plant life were seen on any of the exposures.

Since air temperatures in the area never rise above freezing, no water is available to form streams or lakes. Hence, no erosional features caused by running water are present. In addition, little chemical erosion seems to occur. The dominant erosional process is the scouring and abrasive action of the ice cap flowing around the peaks and of the valley glaciers that have formed within the mountains and, carrying debris from the mountains, drain out to meet the ice cap.

Geologic Structure

The elevation and shape of the Horlick Mountains is governed by uplift and tilting of major blocks of the earth's crust along great faults, or crustal fractures, which created the steep, 5000- to 10,000-foot escarpments bordering the mountains on

the north. These faults follow the trend of the fault system that produced the escarpments of the Queen Maud Range, the Royal Society Range, and the mountains bordering Victoria Land on the west.

The Horlick Mountain faults may be extensions or continuations of this extensive fault system, which is associated with the Antarctic Horst. (A horst is a linear block of the earth's crust that has been uplifted along faults.) The fault blocks in the Horlick Mountain region have maximum elevations along their northern rims, and the surfaces of the sedimentary strata are tilted slightly to the south (with slopes of 5°–15°). Faulting south of the range appears to be of lesser magnitude than that to the north. The general structural aspect of the range is that of a tilted block with a steep, fault-line escarpment on the north and smaller faults on the south.

Transverse faulting of large magnitude is probably responsible for the termination of the central range on the east and west and for the lateral off-setting of the front of the range, since the escarpment bordering the eastern half of the central range is farther south than that of the western half. (The western Horlick range presents the same aspect.) Minor faults appear to parallel the main escarpment.

The rock strata of Mount Glossopteris are relatively undisturbed and dip 3°–20° toward the south. The only break in the general dip is in a local fault zone on Mount Glossopteris, where dips as high as 40° to 50° were measured. The attitudes of the beds were generally consistent throughout. Moreover, no major unconformities other than that between the base of the sediments and the surface of the basement rocks were observed. Hence, it is assumed that the rock sequence from the basement rocks to the Upper Beacon series on the summit of Mount Glossopteris is continuous.

Rock Types

A detailed study was made of the sequence of rock layers—the "stratigraphic section"—at 84°44.8′ S, 113°44′ W, in the central Horlick range. The stratigraphic section (Table 1) begins where Mount Glossopteris protrudes through the ice cap, about three miles south of the base camp (Fig. 6), and ends at the summit.

The section discussed here was selected for study because the horizon of contact between the overlying sedimentary rocks and the basement rocks was near ice-cap level, thus exposing a greater thickness of sedimentary rocks than is generally found elsewhere. Western portions of the range, on the other hand, consist almost entirely of granitic rocks, as the western mountain blocks were raised to higher altitudes by the faulting, and the overlying sediments were subsequently almost completely eroded away.

Basement Rocks: The granitic "basement" rocks—underlying and older than all others in the region—crop ont along the entire length of the Horlick Mountains. The weathered surface of the granitic basement rock has a brownish appearance from a distance. Fresh specimens have been identified as quartz monzonite—an igneous rock formed at great depth and having quartz and both plagioclase and orthoclase feldspar as major constituents. The rock is pinkish in color, contains considerable biotite, and is porphyritic in texture, having crystals of pink orthoclase up to two inches long in the finer-grained groundmass of the rock. Lighter and darker dike-like masses (see below) of igneous rock cut through the quartz monzonite in places.

The upper surface of the basement rock is gently rolling and appears to be an old erosion surface that was later submerged beneath encroaching seas and upon which the overlying sediments were subsequently deposited.

Oldest Sediments: Directly above the basement rocks lies an 1175-foot-thick sequence of Devonian sediments, consisting primarily of graywackes—sandstone-like rocks, predominantly gray in color and

Table 1. Mount Glossopteris Rock Sequence

Rock Unit	Description	Thickness (in feet)	Geologic Period and Age (in millions of years)*
Upper Beacon	Sandstone, shale, coal beds, Glossopteris fossils	1860	Permo-Carboniferous (180-255)
Lower Beacon	Sandstone, shale, a few coal beds	490	Carboniferous (205-255)
Unnamed formation	Dark-gray, silty shale	385	?
Unnamed formation	Graywacke, sandstones, marine fossils	1175	Devonian (255-315)
Basement rocks (unnamed)	Granitic rock	?	Early Paleozoic or Precambrian (510+ if Precambrian)

* Age range from beginning to end of period, or periods, is given. Ages after chart of Major Stratigraphic and Time Divisions in Use by the U. S. Geological Survey, 1958.

commonly made up of fragments of the debris of other rocks. The lowest layer of this sequence consists of 90 feet of poorly-sorted, quartz-feldspar sandstones and finer, silty beds. Some of the sandstone beds in this lower layer contain calcium carbonate cementing material and brachiopod fossils characteristic of Lower Devonian age (see Table 1).

Lying conformably (parallel and with no indication of an intervening erosional interval) upon these basal sedimentary rocks are beds of graywacke approximately 910 feet thick. The graywacke is mostly medium to dark gray, poorly sorted, and contains occasional 10- to 30-foot-thick beds of more resistant rock which form step-like features in the graywacke. The base of the graywacke series is marked by a poorly-sorted boulder conglomerate, with boulders up to one foot in diameter as well as quartz and other smaller rock grains. At the upper boundary of this series is a platy, silty shale, 175 feet thick, which breaks neatly along bedding planes and forms flat, pavement-like surfaces. Fossil worm burrows were found in the platy shale. The graywacke series and the platy shale are Devonian in age (see Table 1).

Dark-Gray Shale: Above the platy shale is another shale sequence. It is very dark gray in color, splits easily along closely spaced, parallel planes, and crumbles easily. This shale unit is 385 feet thick and is quite uniform throughout. It is characteristically soft and easily eroded.

The Beacon Group: The Beacon group, lying between the dark-gray shale and the summit of Mount Glossopteris, is the best known of all Antarctic sedimentary rock units. Exposures of rocks of the Beacon group occur along the entire length of the mountainous belt known as the Antarctic Horst. Their wide distribution in Antarctica is further suggested by the discovery of similar rocks in the Theron Mountains, in Coats Land on the east side of the Weddell Sea, by the British Trans-Antarctic Expedition.

The Beacon group was named by H. T. Ferrar, geologist with the British National Antarctic Expedition, 1901–04. In outcrops in the McMurdo Sound area Ferrar noted the nearly horizontal attitude of the beds, their sandy composition, and that they contain plant fossils. He also noted that the Beacon group is intruded in many places by sills and dikes of "dolerite." (Sills and

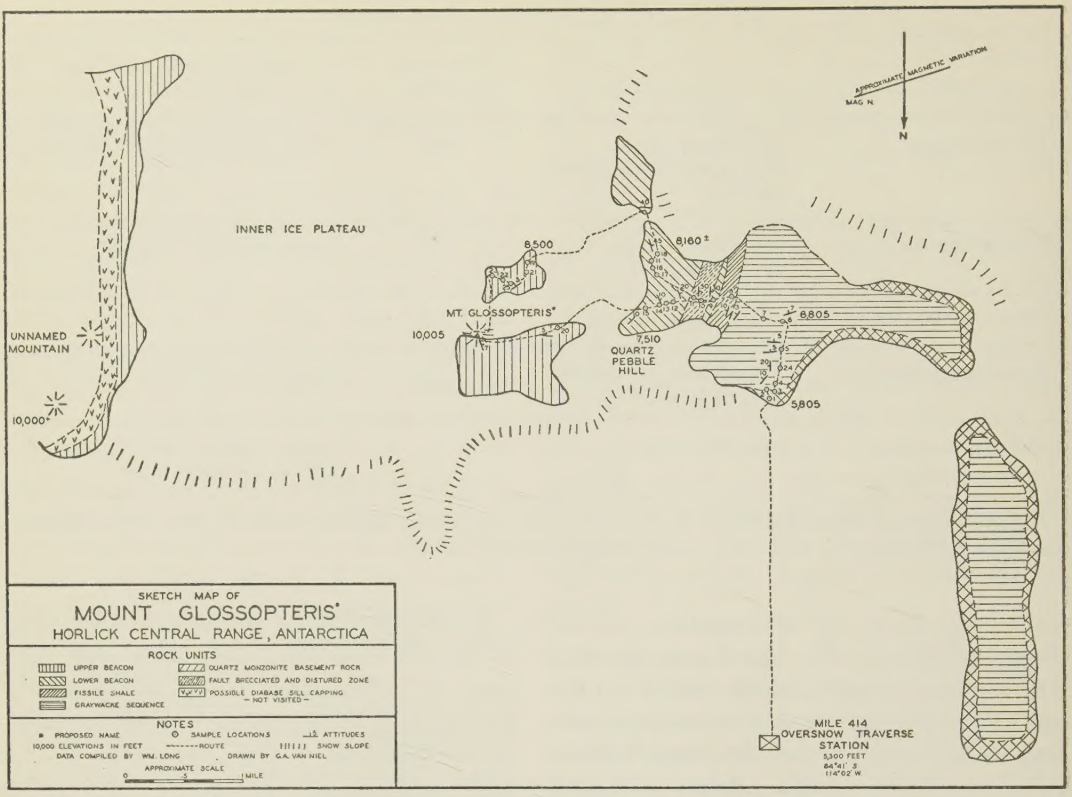

Fig. 6. *Reconnaissance Geologic Map of Mount Glossopteris Region, in the Central Range of the Horlick Mountains. By W. E. Long.*

dikes are igneous materials intruded in the molten state into older rock formations; sills are parallel to the bedding or foliation planes of the intruded rocks, while dikes cut across them. Dolerite is rock of basaltic composition.) Since then, nearly every expedition to this portion of Antarctica has found the Beacon to be as originally described. In other areas of Antartica, the diabase (dolerite) sills reach thicknesses of 2000 feet and account for more than half of the total bedrock thickness. The Beacon group in the central range of the Horlick Mountains, however, differs from occurrences in other areas in that no diabase is present (with one possible exception, described below). In all other respects the Beacon in the central Horlicks resembles descriptions of it from other localities.

The upper limit of the Beacon group has been removed from the summit of Mount Glossopteris by erosion. A mountain a few miles from Mount Glossopteris showed a change in rock types in the upper 200 feet. This capping rock appeared to have igneous features and could, therefore, be a diabase sill capping the Beacon group. On the basis of relative positions, the summit of Mount Glossopteris appears to be near the top of the Beacon group, as seen on the nearby mountain.

Plant fossils (*Glossopteris* leaves and *Dadoxylon* wood) and small beds of coal and shale have also been described from all exposures of the Beacon group. The sandstones commonly show cross-bedding and current ripples, indicating that deposition took place under terrestrial conditions in an arid climate and that the source area was relatively near at hand.

The Upper Beacon is cyclic in nature, with sequences of sandstone, shale, and coal beds being repeated several times through a section 1860 feet thick. The coal beds, ranging in thickness from about one inch to one foot, are usually closely associated with slates. Cross-bedding and plant remains are common in the sandstone. The largest of the plant stems found was approximately 12 feet long and more than 12 inches in diameter. The cyclic nature of the Upper Beacon and the relative abundance of coal beds are not characteristic of the Lower Beacon.

Geologic History

Basement Rocks: The oldest rocks exposed in the central Horlick Mountain region are the quartz monzonite basement rocks. This intrusive igneous material was probably emplaced beneath the earth's surface in early Paleozoic or Precambrian time. Erosion then removed the overlying rocks and produced the rolling surface on which the younger sedimentary rocks were later deposited.

Sedimentary Deposits: The sedimentary rocks in the Horlick region form a sequence typical of the continental side of a geosyncline. (Geosynclines are extensive, usually linear regions of subsidence in the earth's crust in which great thicknesses of sediments and volcanic materials, carried down from bordering land areas, slowly accumulate.) The earliest sedimentary rocks in this region probably represent beach deposits layed down by an encroaching sea during the early Devonian period. The continuing land subsidence that permitted this marine encroachment was accompanied by uplift of bordering regions, which served as sources for the graywackes that were being poured into the subsiding basin.

The coarser rocks of the Lower Beacon group, which were the next to be deposited, probably reflect lowering of the source areas by erosion, filling of the basin, retreat of the seas, and the on-set of an environment that was swampy and marshy or, possibly, predominantly terrestrial. Minor fluctuations of the base level of erosion probably account for the cyclic nature of the Upper Beacon. The plant fossils of the Beacon indicate that the Horlick Mountain region was dry land again during the Carboniferous and Permian periods.

Post-Depositional History: After the Carboniferous and Permian periods, the Horlick Mountain region remained generally above sea level. The present position of the mountains may reflect several periods of uplift, the most recent of which took place in the Tertiary or Quaternary periods (i.e., within the last 60 million years), when the last upheaval raised and tilted the blocks to form the present mountains.

Summary and Conclusions

Rocks collected from outcrops in the central range of the Horlick Mountains, by members of the 1958–59 IGY oversnow traverse from Byrd Station, apparently represent a continuous, nearly undisturbed sequence, the upper portion of which has been named the "Beacon group" in other Antarctic localities.

Beneath the Beacon sediments is a sequence of fossiliferous Lower Paleozoic marine rocks. It appears that the only other fossiliferous Paleozoic marine rocks found in the Antarctic have been erratics—rocks moved from their places of origin, usually by ice—containing Cambrian (430–510 million years ago) and Devonian fossils.

Rocks resembling the graywacke of the Horlick Mountains have also been observed in other parts of Antarctica and it has been suggested that some of these may be Paleozoic in age; unfortunately, these rocks do not contain fossils and are therefore difficult to date.

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